NS102 Lecture 12

20th Century Icons featured in today's lecture

Einstein

Hubble

Elvis

Frog Action Photos

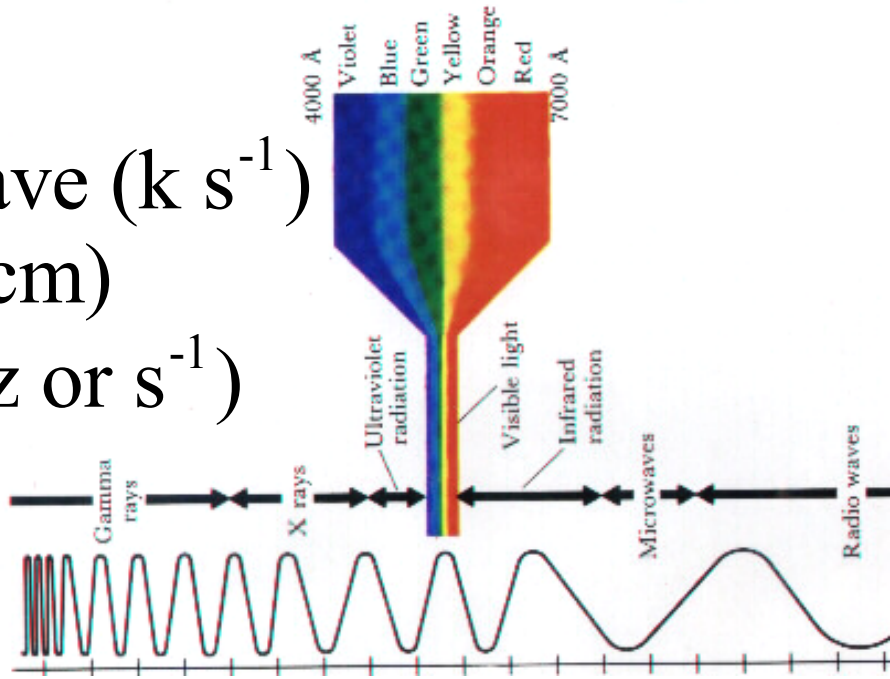
News of the week

- No office hours Thursday
- Lab this week: 2nd week of geometry of the universe
- Exam #2: May 20th
- Final Exam:

Facts about light

1. Light is a wave

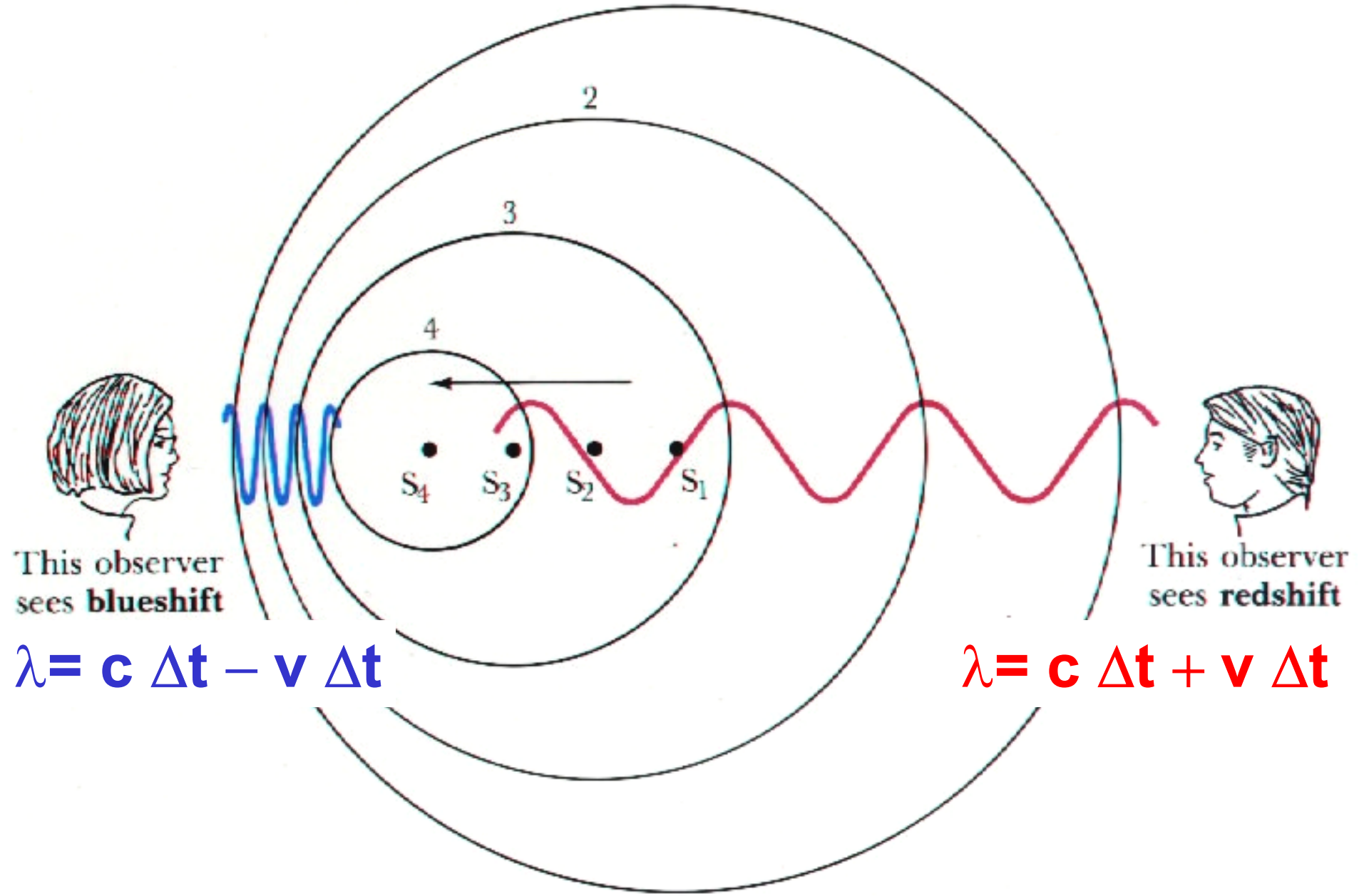
$$c = \lambda \nu \quad \begin{cases} c = \text{ velocity of wave (k s}^{-1}) \\ \lambda = \text{ wavelength (cm)} \\ \nu = \text{ frequency (Hz or s}^{-1}) \end{cases}$$



2. The wavelength is quantized

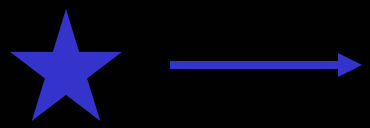
Visible Emission Spectrum

3. Doppler shift

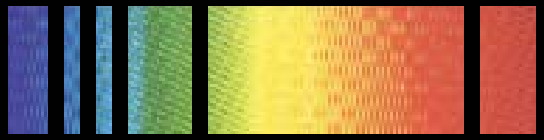


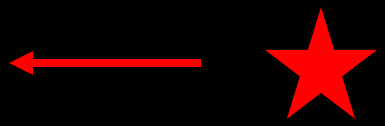
$\lambda = c\,\Delta t - v\,\Delta t$

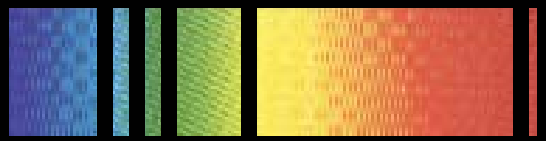
$\lambda = c\,\Delta t + v\,\Delta t$



blue shift







red shift

$$\lambda = c\,\Delta t \pm \mathrm{v}\,\Delta t$$

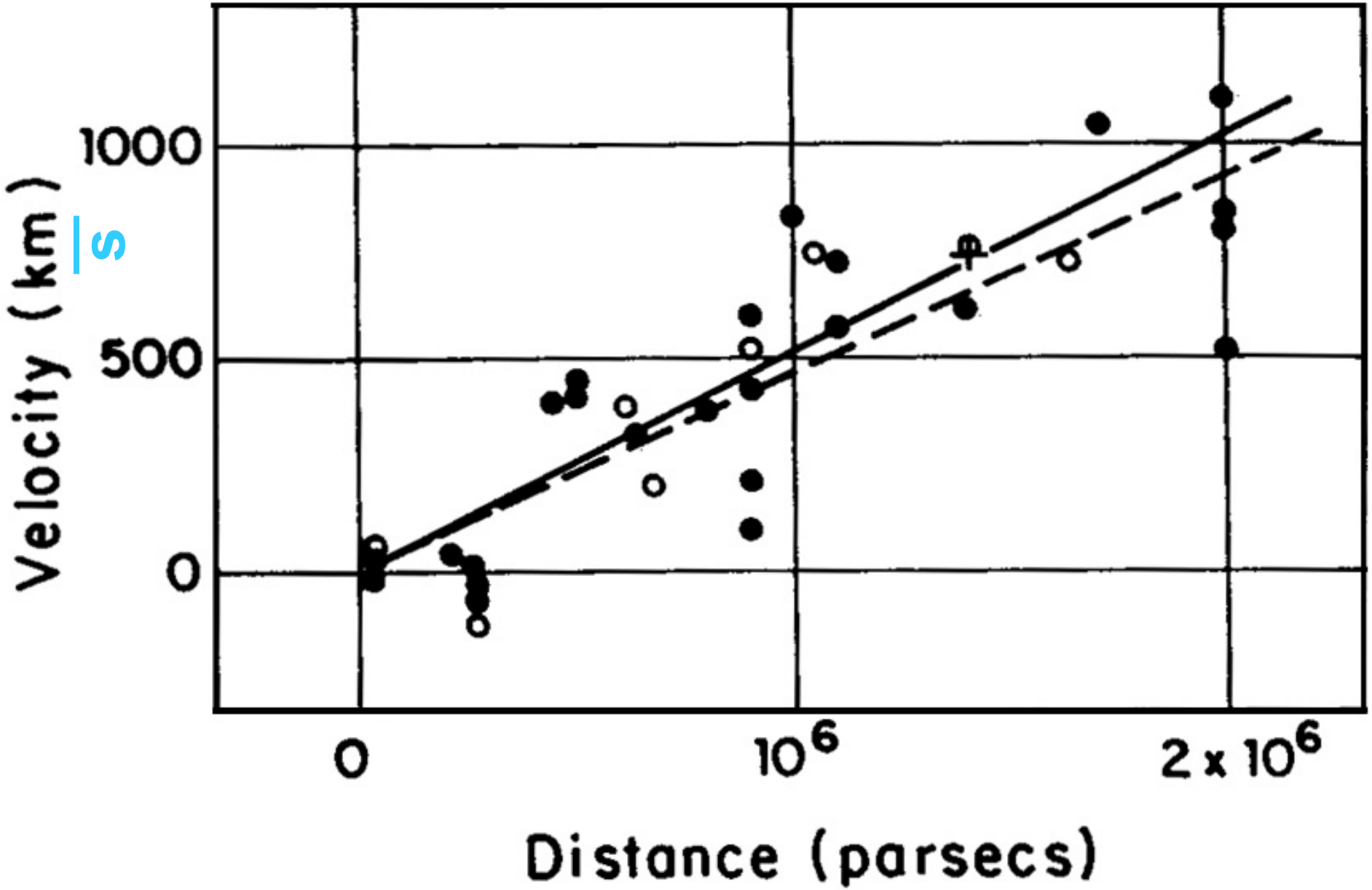
$$c\,\Delta t = \lambda_0 \qquad \Rightarrow \qquad \lambda = \lambda_0 \pm \mathrm{v}\,\Delta t$$

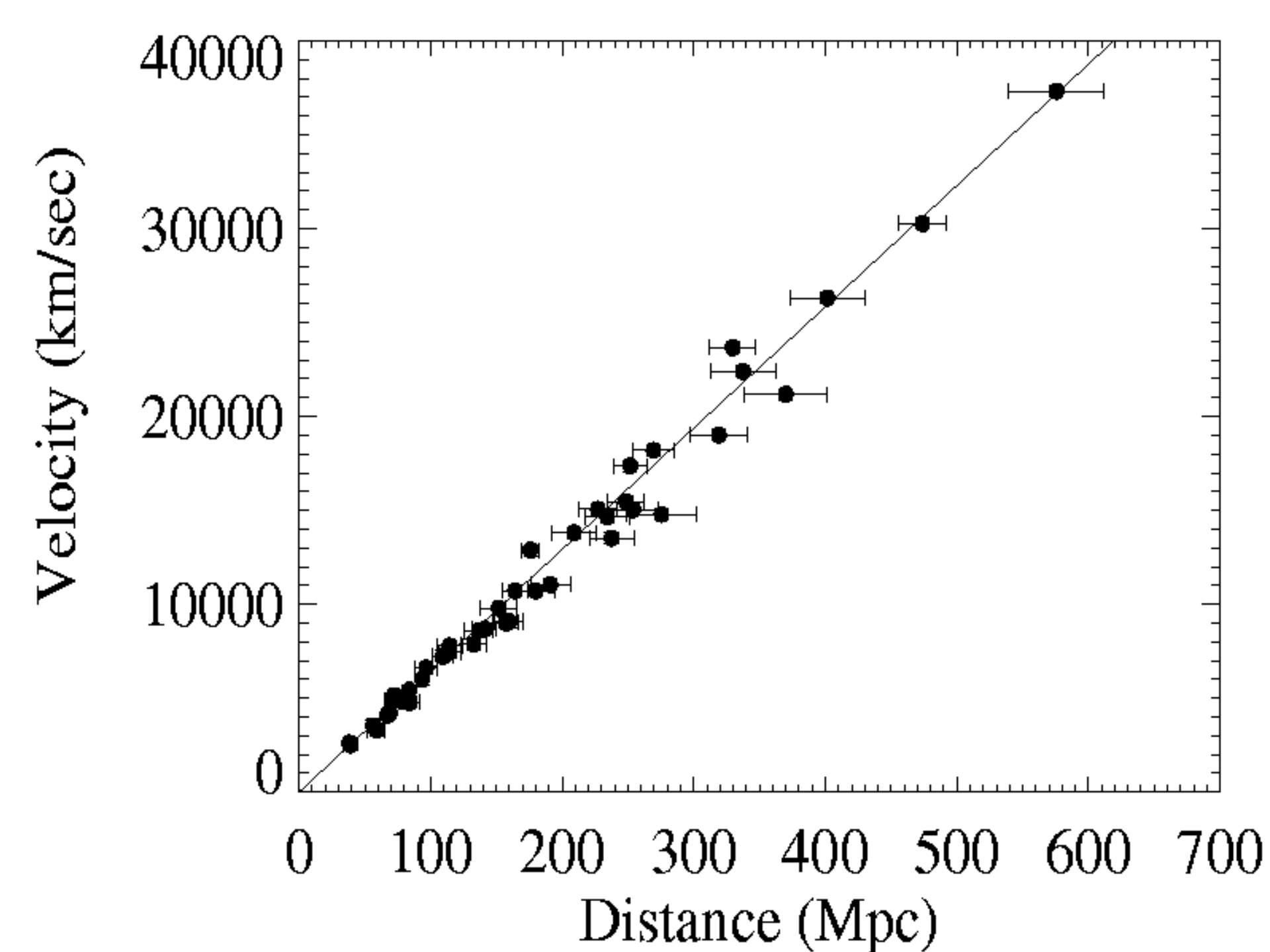
$$\Delta t = \frac{\lambda_0}{c} \qquad \Rightarrow \qquad \lambda = \lambda_0 \pm \frac{\mathrm{v}}{c}\lambda_0$$

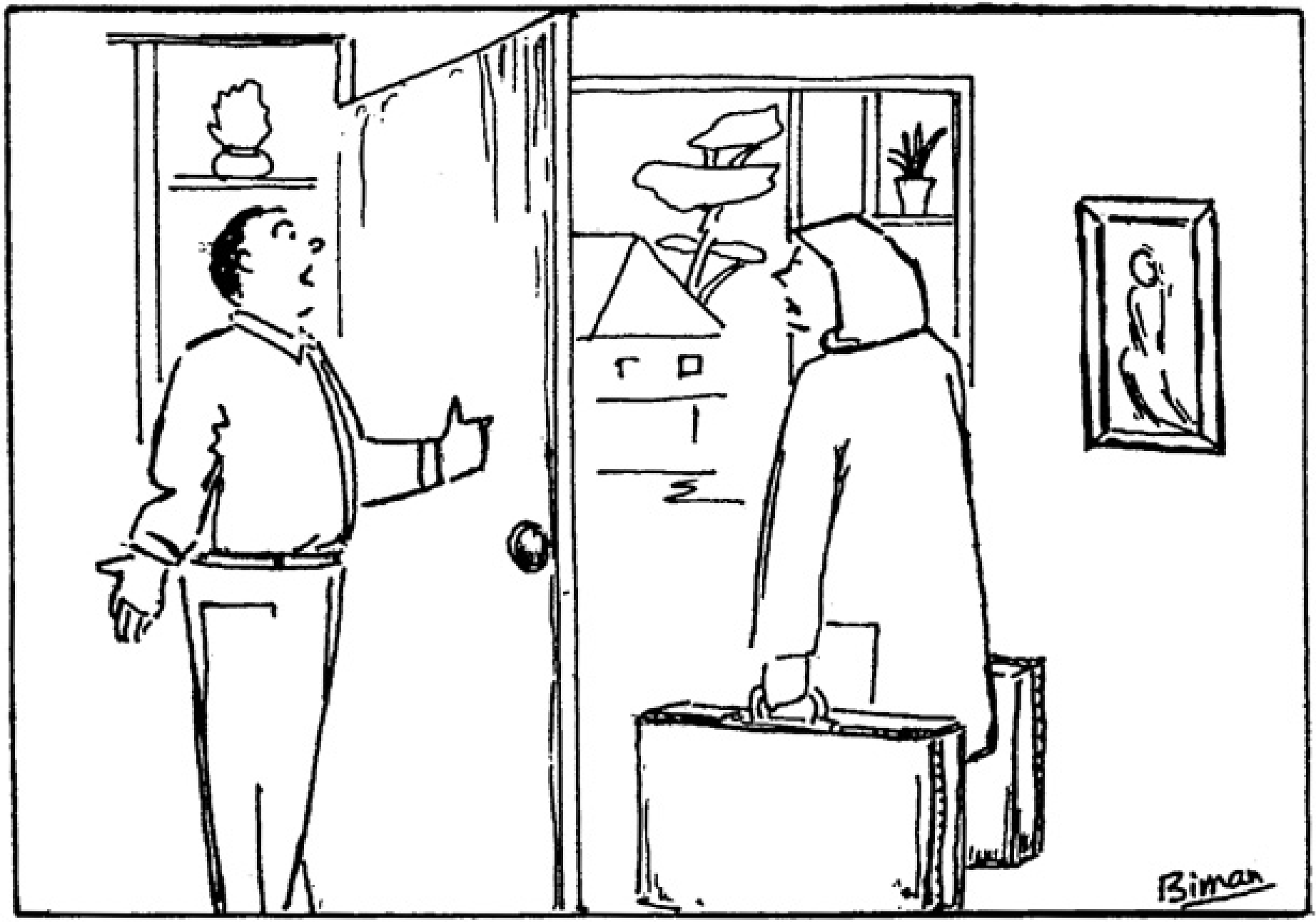
$$\boxed{\frac{\lambda}{\lambda_0} = 1 \pm \frac{\mathrm{v}}{c}}$$

Edwin Hubble
1884 - 1953

Hubble's Discovery Paper - 1929




40000
30000
20000
10000
0
Velocity (km/sec)
0
100
200
300
400
500
600
700
Distance (Mpc)



"THE HUBBLE CONSTANT? I WOULDN'T HAVE THOUGHT THAT WOULD EVER COME BETWEEN US!"

$$v = H_0 d$$

H_0 = Hubble's constant

$H_0 = 500$ km s^{-1} Mpc^{-1}	**Hubble**	**1929**
$H_0 = 100$ km s^{-1} Mpc^{-1}		**1960s**
$H_0 = 55$ km s^{-1} Mpc^{-1}		**1970s**
$H_0 = 65$ km s^{-1} Mpc^{-1}		**1990s**
$H_0 = 72$ km s^{-1} Mpc^{-1}		**2001**

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Cinnamon & Spice
All Natural Flavors

FACT OR FICTION

SCIENCE

The universe is shrinking and will soon be the size of a golf ball.

See other side for answer.

CONVENTIONAL DIRECTIONS

Empty packet into bowl.
Add **1/2 cup** boiling water; stir.

MICROWAVE DIRECTIONS

Empty packet into microwaveable bowl.
Add **2/3 cup** water or milk.
Microwave at **HIGH** about 1-2 minutes; stir.
Use care when removing cereal from microwave; bowl may be hot.

For **thicker** oatmeal decrease liquid; for **thinner** oatmeal increase liquid.

THE ANSWER

Fiction! Most stars and galaxies are moving away from the earth which means the universe is actually getting bigger.

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FACT OR FICTION

SCIENCE

Sir Isaac Newton discovered gravity by watching an apple fall.

See other side for answer.

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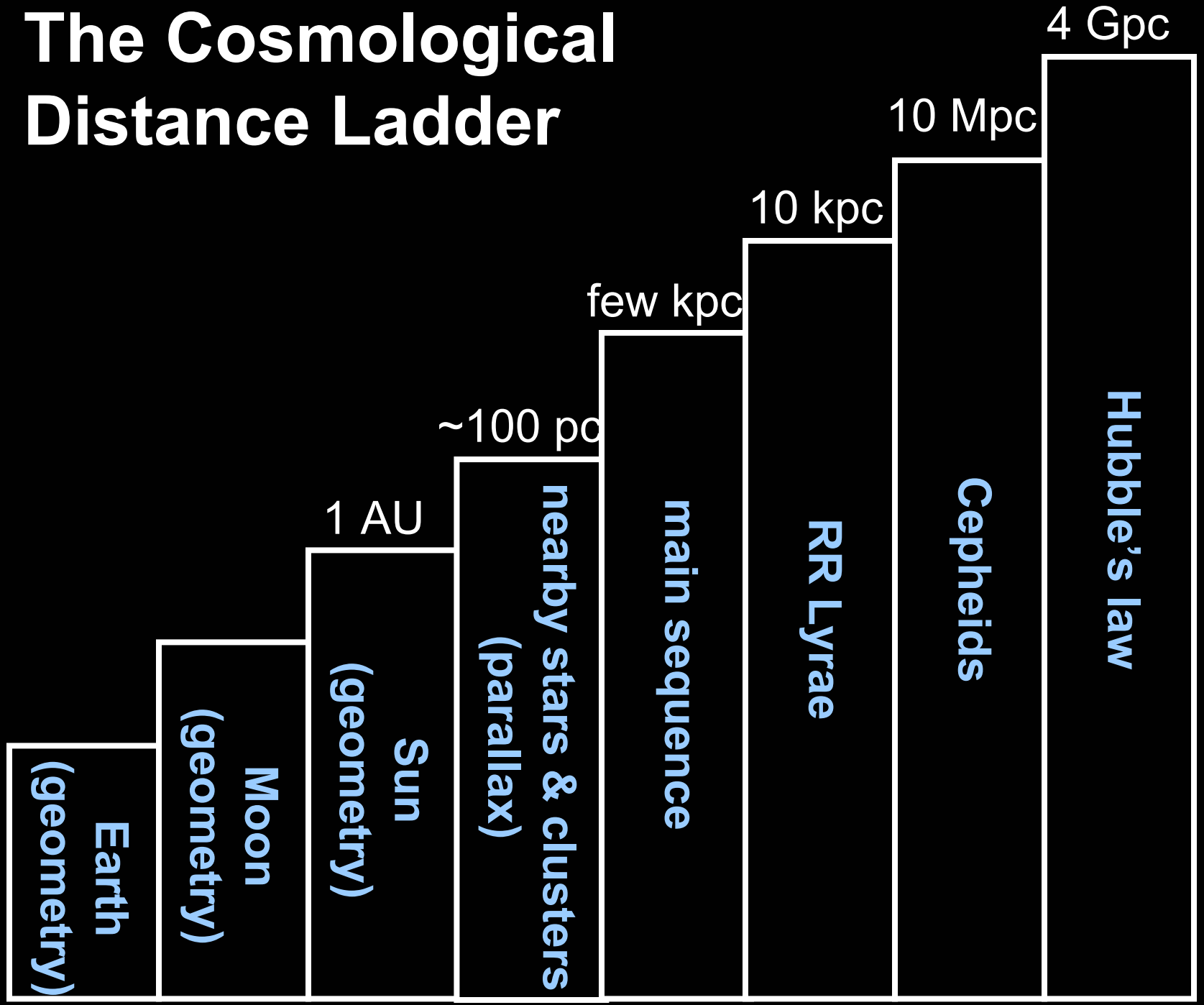
THE ANSWER

Fact! Newton made his famous discovery as a young man but was unable to prove it until almost 20 years later.

The Cosmological Distance Ladder



The red shift

$$\frac{\lambda}{\lambda_0} = 1 + \frac{v}{c}$$

λ **detected wavelength**

λ_0 **emitted wavelength**

v **recessional velocity**

c **velocity of light**

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{v}{c}$$

$$c = 3 \times 10^5 \text{ km s}^{-1}$$

$$v = H_0 d$$

H_0 = Hubble's constant

Let's assume $H_0 = 100\ \text{km s}^{-1}\ \text{Mpc}^{-1}$

$$v = 100 \frac{\text{km}}{\text{s}} \frac{d}{\text{Mpc}}$$

v	d
$100\ \text{km s}^{-1}$	1 Mpc
$1{,}000\ \text{km s}^{-1}$	10 Mpc
$10{,}000\ \text{km s}^{-1}$	100 Mpc
$100{,}000\ \text{km s}^{-1}$	1,000 Mpc

$$\lambda = 6{,}000 \ \text{Angstroms}$$

$$\lambda_0 = 5{,}000 \ \text{Angstroms}$$

$$\frac{\mathrm{v}}{c} = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{1000}{5000} = 0.2$$

$$\mathrm{v} = 0.2c \ \Rightarrow \ \mathrm{v} = 60{,}000 \ \mathrm{km\ s^{-1}}$$

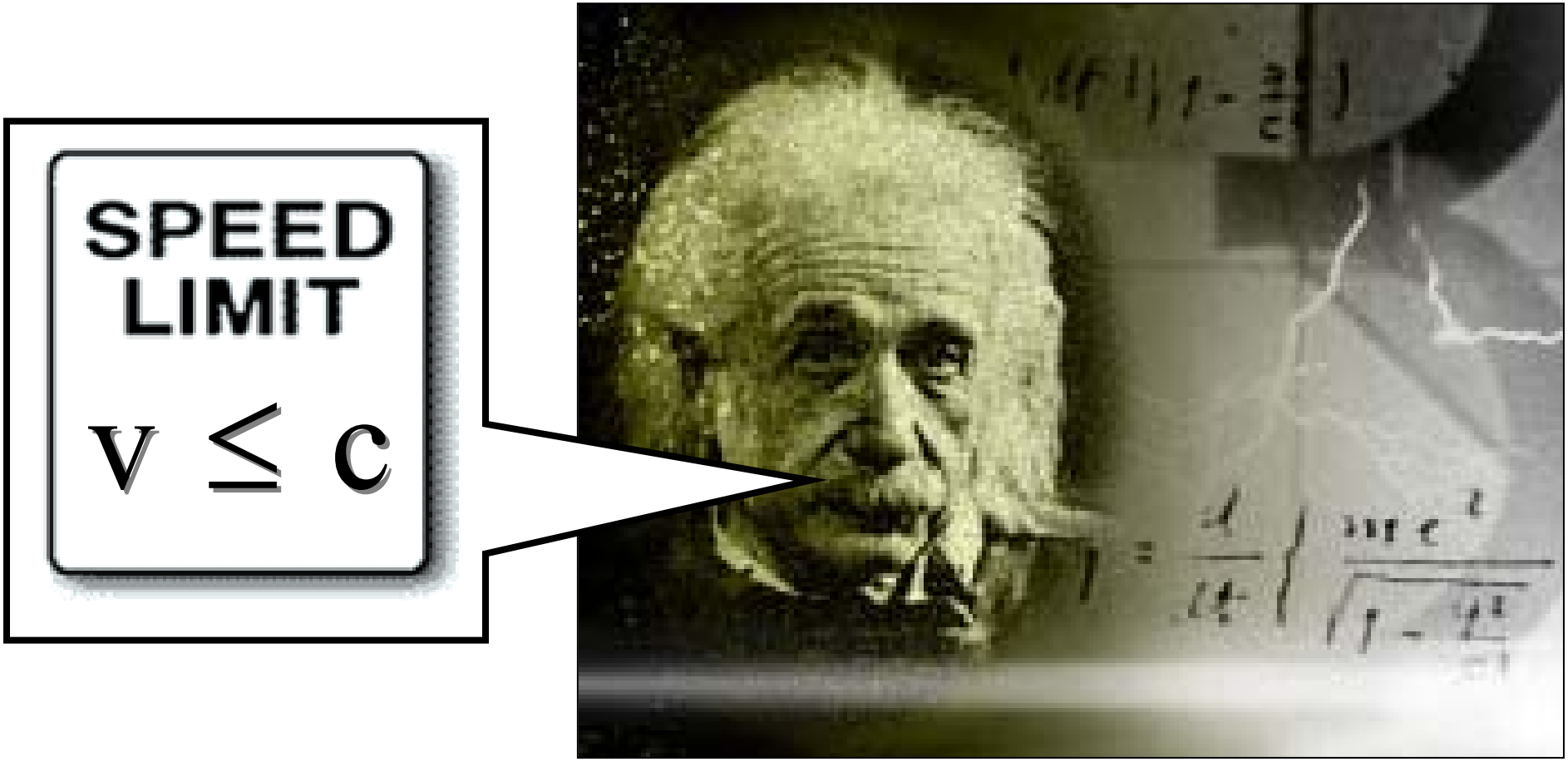
$$\lambda = 15,000 \text{ Angstroms}$$

$$\lambda_0 = 5,000 \text{ Angstroms}$$

$$\frac{\mathrm{v}}{c} = \frac{\lambda - \lambda_0}{\lambda_0} = \frac{10,000}{5,000} = 2$$

$$\mathrm{v} = 2c \quad \Rightarrow \quad \mathrm{v} = 600,000 \text{ km s}^{-1}$$

$$c = 300,000 \text{ km s}^{-1}$$



Relativistic redshift equation

$$z = \frac{\lambda - \lambda_0}{\lambda_0}$$

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1} = \frac{z^2 + 2z}{z^2 + 2z + 2}$$

$$\approx \frac{2z}{2} = z = \frac{\lambda - \lambda_0}{\lambda_0} \qquad (z << 1)$$

$$\approx \frac{z^2}{z^2} = 1 \qquad (z >> 1)$$

We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe (no center)
- no special set of points (no edge)

In the field of modern cosmology, the first principle is called the “Cosmological Principle. It states that the universe has no center, that it has the same properties throughout. Every place in the universe has, in this sense, equal rights. How can the human race, which has evolved in a universe of such fundamental equality, fail to strive for a society without violence and terror? How can we fail to build a world in which the rights of every human from birth are respected?

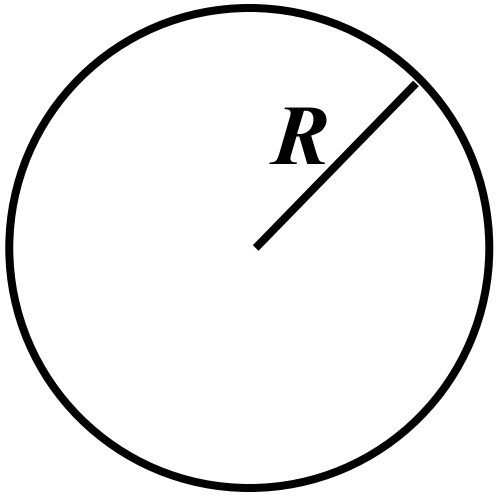
Fang Li Zhi
Acceptance speech
for the
Robert F. Kennedy
Memorial Human
Rights Award

Spaces that obey the cosmological principle:

1-dimension:

^1R  x

$$V = \int_{-\infty}^{\infty} dx = \infty$$

^1S 

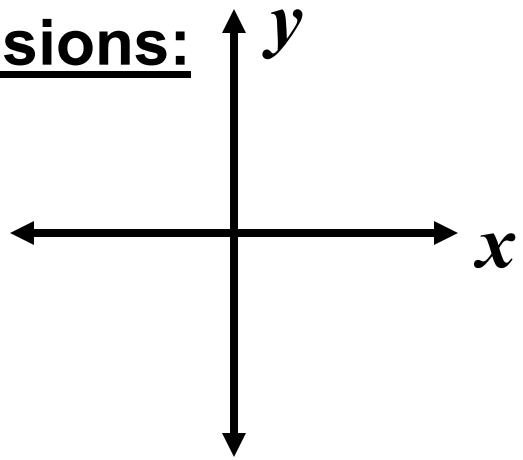
$$V = R\int_0^{2\pi} d\phi = 2\pi R$$

$$x^2 + y^2 = R^2$$

Spaces that obey the cosmological principle:

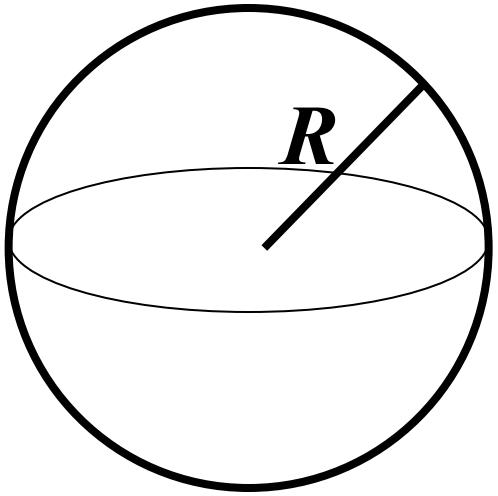
2-dimensions:

^2R



$$V = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy = \infty$$

^2S



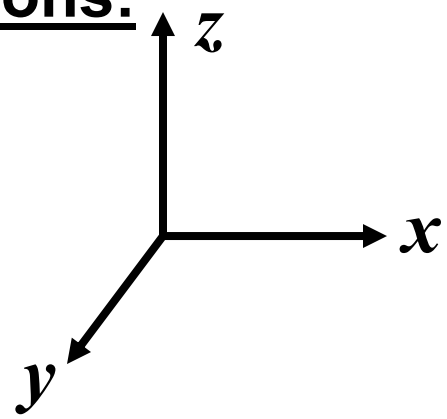
$$V = R^2 \int_0^{\pi} \sin\theta \, d\theta \int_0^{2\pi} d\phi = 4\pi R^2$$

$$x^2 + y^2 + z^2 = R^2$$

Spaces that obey the cosmological principle:

3-dimensions:

^3R

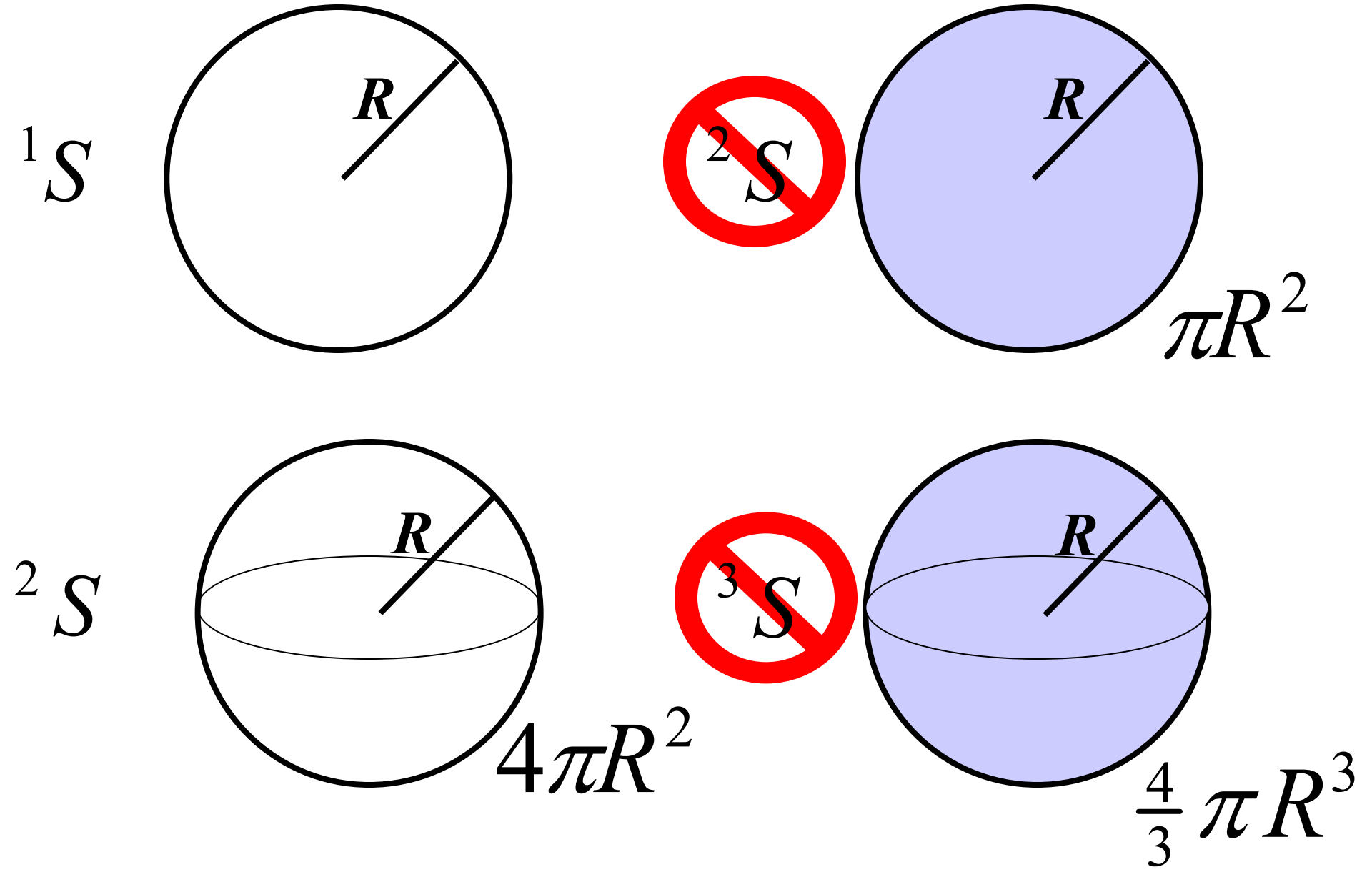


$$V = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy \int_{-\infty}^{\infty} dz = \infty$$

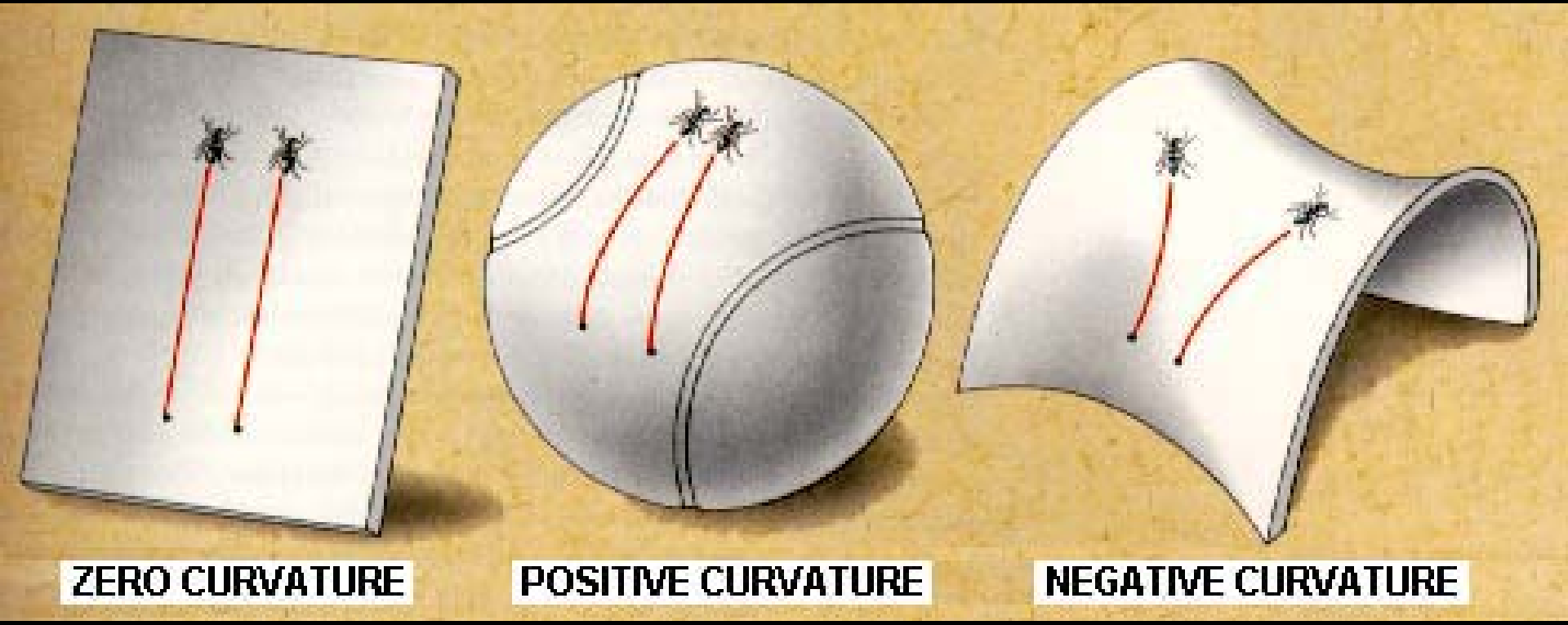
^3S

$$V = R^3 \int_0^{\pi} \sin^2 \chi \, d\chi \int_0^{\pi} \sin\theta \, d\theta \int_0^{2\pi} d\phi = 2\pi^2 R^3$$

$$x^2 + y^2 + z^2 + w^2 = R^2$$

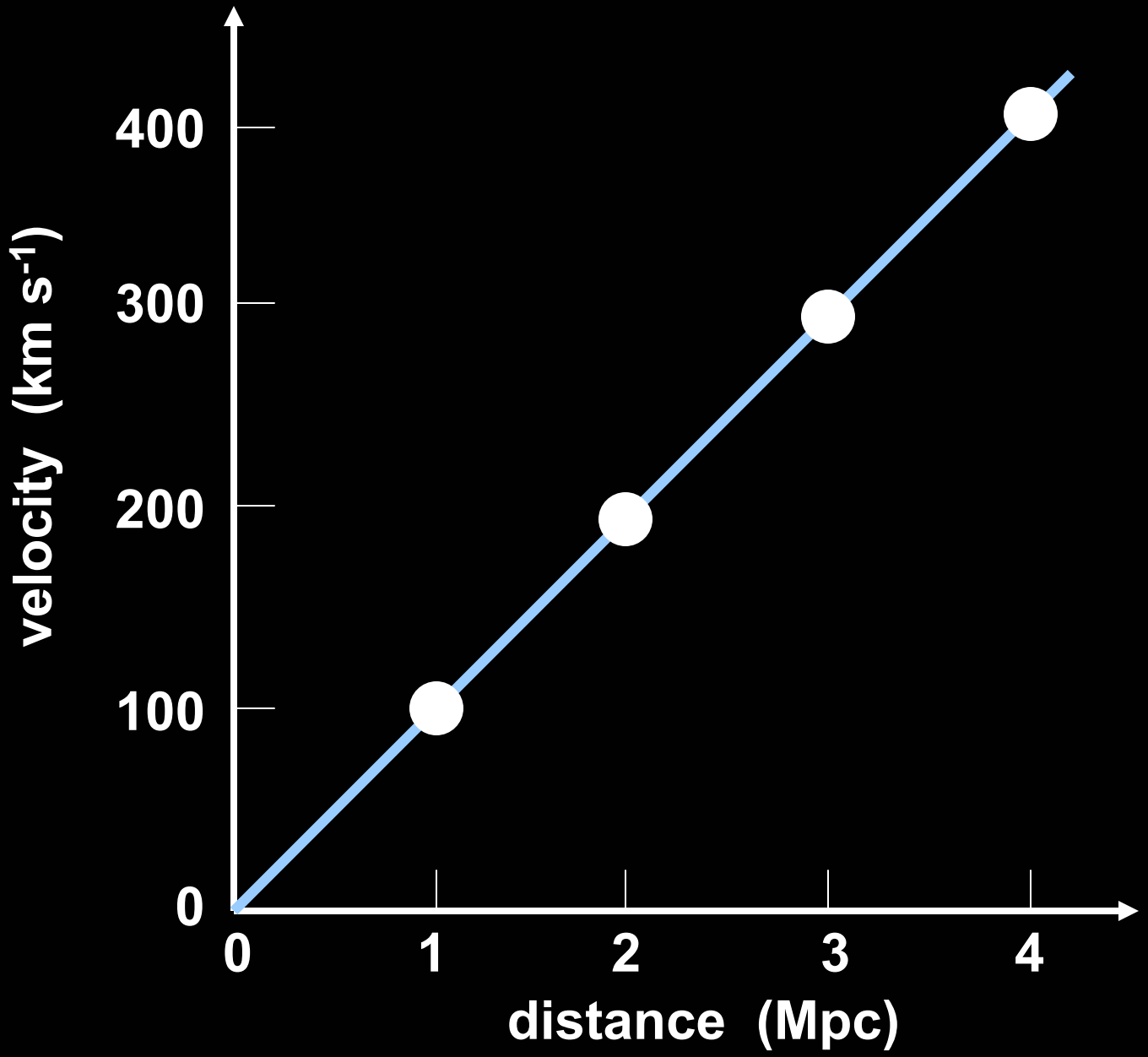

^1S
R
^2S
R
πR^2
^2S
R
$4\pi R^2$
^3S
R
$\frac{4}{3}\pi R^3$

^3R ^3S ^3H



FLAT SPHERICAL HYPERBOLIC

Hubble's Law: $v = H_0 d$ (H_0=100 km s^{-1} Mpc^{-1})



The Hubble age of the universe

$$d = \mathrm{v}t \qquad \text{distance} = \text{velocity} \times \text{time}$$

$$d = \mathrm{v}H_0^{-1} \quad \text{Hubble's law}$$

$$\Big\} \; t = H_0^{-1}$$

$$H_0 = 100h \ \mathrm{km}\,\mathrm{s}^{-1}\,\mathrm{Mpc}^{-1} \times \frac{1\ \mathrm{Mpc}}{3\times10^{19}\ \mathrm{km}}$$

$$(0.8 \geq h \geq 0.6)$$

$$= \frac{100h}{3\times10^{19}}\,\mathrm{s}^{-1} \times \frac{3\times10^{7}\ \mathrm{s}}{1\ \mathrm{year}}$$

$$= \frac{100h}{10^{12}\ \mathrm{years}} = \frac{h}{10^{10}\ \mathrm{years}}$$

$$t = 10^{10}\,h^{-1}\ \mathrm{years}$$

$$12.5 \leq t \leq 17\ \mathrm{Gyr}$$

$$1\ \mathrm{Gyr} = 10^{9}\ \mathrm{years}$$